

SS Cyg Outburst Predictors and Long Term Quasi-Periodic Behavior

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ABSTRACT

We report null results on a two year photometric search for outburst predictors in SS Cyg. Observations in Johnson V and Cousins I were obtained almost daily for multiple hours per night for two observing seasons. The accumulated data are put through various statistical and visual analysis techniques but fails to detect any outburst predictors. However, analysis of 102 years of AAVSO archival visual data led to the detection of a correlation between a long term quasi-periodic feature at around 1,000-2,000 days in length and an increase in outburst rate.

Subject headings: Stars

1. Introduction & Prior Work

SS Cyg is one of the most popular and studied variable stars. It is a cataclysmic variable (CV-a.k.a dwarf novae) of the U Gem (UG) class, and prototype of the SS Cyg (UGSS)

subclass (Kholopov 1985). UG class CVs are a binary system consisting of a late main sequence secondary star orbiting a white dwarf primary. The secondary star continuously fills its Roche lobe and transfers mass to the primary, which forms an accretion disc around the primary as angular momentum is conserved and spread within the disc. Occasionally the accretion disc flares up into a bright state referred to as an "outburst". The UGSS subclass have outbursts that are usually separated on the order of months, but are largely unpredictable. Outbursts typically have an amplitude of 2-6 magnitudes and last a few days to a few weeks.

The most popular fundamental model for the outburst mechanism in UG stars is the disk instability model first proposed by Osaki (1976). In it, the region where the in-falling matter hits the accretion disc, known as the hot spot, reaches a critical mass. This is a result of a higher rate of mass transfer from the secondary to the disc than from the disc to the white dwarf (due to viscosity). When the leftover material reaches a critical mass, the accretion disc becomes unstable. Viscosity increases, along with the mass transport rate, through the disc. Both increases are driven by angular momentum. Eventually the system blazes in additional light as the mass built up emits energy due to enhanced ionization of Hydrogen. Only about 3-10% of the material from the disc actually falls onto the white dwarf (see panel 3 of figure 13 in Cannizzo [1993]).

1.1. Outburst Types

SS Cyg's quiescence magnitude is around $v=12$. Outbursts are usually expected every 4-10 weeks, with a duration of 7-18 days each (Jevtic, Mattei & Schweitzer 2003). During outburst, the star reaches maximum light near magnitude $v=8$. Cannizzo and Mattei (1992) describe the outbursts as bimodal with long outbursts typically lasting >12 days and short outbursts lasting <12 days. They assigned the letter "L" to the long outbursts and "S" to the short and anomalous outbursts. The anomalous outbursts tend to have a linear, lower rate of change and smaller amplitude than long and short outbursts (Figure 1). They found the most common sequence as LS (with 134 occurrences), LLS (69), LSSS (14), and LLSS (8). About 89% of all outbursts can fall into one of these four sequences.

1.2. Outburst Cycles & Periodicity

Honey et al. (1989) photometrically observed SS Cyg over a single long and a single short outburst cycle. They reported substantial flickering on the order of minutes but were unable

to find any modulation (including near the orbital period) or periodicity to an amplitude limit of 0.05 magnitude. Giovannelli, Martinez-Pais and Graziati (1992) review the flickering behavior of SS Cyg in both outburst and quiescence, but find no correlation with outburst type, although they do find an inverse correlation between flickering amplitude and system brightness.

Cannizzo and Mattei (1992) analyzed the historical light curve of the American Association of Variable Star Observer’s (AAVSO) International Database (hereafter: AID), which at the time included 29,387 individual daily means from 1896 September 27 to 1992 April 7. They found no correlation between outburst duration time and cycle time but did confirm a correlation between quiescent magnitude and cycle time, caused by a variation in the mass transfer rate of up to a factor of 2 on yearly time scales and a variation of 20%-30% on decadal time scales. They did not find any periodicity in cycle time.

In a later study (Cannizzo & Mattei 1998), using a smaller subset of the data (1963 - 1997), they discovered a variable decay rate in some outburst declines. In a minority of the outbursts, the decay rate slows down about two-thirds of the way into the decline for about a day and a half, then the decay returns to its previous rate. The significance of the break is proportional to the length of the total decline. The break manifests itself as a 20%-300% decrease in the decay rate for around one day. Cannizzo and Mattei (1998) refers to this phenomenon as a ”glitch”, we refer to it hereafter as the ”Cannizzo Glitch”.

Ak et al. (2001) analyzed the quiescence magnitude and outburst cycles of 23 dwarf novae mostly using Fourier analysis. They found no correlation between outburst cycle period and masses of component stars, mean outburst interval, mean outburst duration, mean decline and rise rates of outbursts, absolute quiescent magnitudes and outburst states.

In a poster, Hill and Waagen (2005) suggested the existence of a pre-outburst brightening of about 2% over the course of around 12 hours followed by a plateau which lasts another 12 hours leading up to the onset of the outburst. The analyzed data set included about half of the AID visual data and excluded CCD observations. This was the only search for predictors found in published literature.

1.3. Long Term Variation

Kiplinger, et al. (1988) report a 0.15 magnitude amplitude, 7.2 year period in the quiescent behavior of SS Cyg, determined through Fourier analysis of one day means in the AID data from 1896 - 1984. Also, Bianchini (1988) discovered a similar 6.9 year period through Fourier analysis of the intervals between outbursts and attributes it to solar type

variation in the secondary (Bianchini 1992).

However, Richman, Applegate and Patterson’s (1994) own analysis of the individual data points plus various long term moving averages find that the power of the reported ~ 7 year period is not significantly greater than that of other low frequency signals in the power spectrum and caution that the reported significance is due to the eye being, ”...very prone to spot one to three cycles of periodic behavior in any randomly varying time series.” However, their analysis excluded all quiescent data points within 12 days on either side of the outburst, thus if the source for the reported ~ 7 year period was found in activity near the outburst then it would be hidden from their analysis.

Hemplemann and Kurths (1990) O-C analysis found secular variation within 100 years as well as deviations from the sample mean over intervals of a few tens of cycles. Jevtic, Mattei and Schweitzer (2003) performed a nonlinear analysis using Poincaré section and found a period of around 52 years. It is unclear whether the two periods are related as a fundamental and a harmonic pair.

2. Observations

SS Cyg was observed in the V and Cousins I (hereafter I_c) (Cousins 1976) bands over 483 nights during a period from May 1, 2005 to February 5, 2007 by AAVSO observers participating in a coordinated campaign. The average length of coverage per observing day was 446 minutes in V and 348 minutes in I_c . In total, 108,612 individual observations in V and 14,292 observations in I_c were obtained from 24 observing locations during the course of the campaign.

Each observer reduced his/her own differential photometry using comparison stars published on an AAVSO chart. The values from those stars were determined via precision photometry obtained over multiple nights using the U.S. Naval Observatory - Flagstaff Station (NOFS) 1.0m telescope along with a large set of Landolt standards (Landolt 1992) having a range of color and airmass. The raw data and reported uncertainties are available for download from the AAVSO web site.

Uncertainty in the individual observations varied widely. When simultaneous data was available, the data with the higher reported uncertainty was excluded. A collective uncertainty for the entire dataset was determined by averaging the observations into one day bins and then adding the standard deviation in quadrature. The result gives an zeropoint uncertainty of 0.1 magnitudes in V and 0.16 magnitude in I_c . This includes both stochastic uncertainty and uncertainty caused by the flickering. When considered separately, most

individual datasets had a stochastic uncertainty (precision) between 0.01-0.05 magnitudes.

In addition to our photometric data, we also analysed 366,614 visual observations available from the AAVSO International Database (Turner et al. 2006). The observations date from May 17, 1904 to July 31, 2006. Previous studies have determined an uncertainty of 0.2-0.3 magnitudes for visual observations while exceptional visual observers can reach a precision of 0.02 magnitudes (Price et al. 2006). The visual bandpass varies by observer, but in general is slightly bluer than V (Collins 1999).

3. Analysis

3.1. Photometric Data

The resulting light curve covers most of the 2005 and 2006 observing seasons (Figure 2). It includes four long outbursts, six short outbursts, and no anomalous outbursts. Inspection of the AAVSO visual light curve confirms no outbursts were missed.

There was considerable flickering in both bands during quiescence (Figure 3). A straight line was removed from a dataset consisting of $(V-I_c)$ measurements converted to flux space (Bessell 1979). No trends were found in either the standard deviation of the coefficients or the residuals of the straight line. Note that due to the flickering in this star, any color not formed from simultaneous observations has built-in error greater than the Poisson or measurement error.

To look for predictors, we folded the V , I_c , $(V-I_c)$ and visual datasets onto a single light curve correlated with the onset of outburst, defined as the first observation greater than 0.1 Jy in V , 0.14 Jy in I_c and 0.25 Jy for visual observations (Figure 4) and which is greater than 20 days since the start of the previous outburst (to filter out observational scatter around the outburst thresholds during the decay). We did not find any consistent predictor in the light curves. We also folded the residuals of the detrended $(V-I_c)$ dataset to look for any change in the flickering rate prior to outburst, but none were found.

A Fourier analysis (Ferraz-Mello 1981) of the quiescent observations is dominated by red noise caused by the flickering (Figure 5). The orbital period was detected at 0.275300 +/- 0.000006 days along with a strong harmonic at 0.13757 +/- 0.000001 days. No other periodic signals were detected. Significance in all Fourier analysis was determined at the 3 sigma level by tripling the standard deviation from the average power of each spectrum computed with the minimum frequency resolution supported by the data.

The Cannizzo Glitch was originally detected in around 1/6 of the outbursts of SS Cyg.

(Cannizzo & Mattei 1998) We did not detect the glitch among our ten analyzed outbursts.

3.2. Visual Data

The AID collection of visual observations was analysed to look for periodicity in the outbursts and quiescence activity which could be a predictor of future outburst behavior. One day means for the complete 102 year visual database were computed in magnitude space so errors will remain unbiased in the magnitude domain rather than becoming biased after transformation into flux space. To look for long term periodicity, such as Kiplinger’s 7.2 year and Bianchini’s 6.9 year periods (hereafter *KB’s*) periods, a Fourier analysis for signals in the 1,000-10,000 day range was computed (Figure 6). It reveals multiple signals, including KB’s periods, but nothing that stands out on its own above background activity levels. This confirms the results of Richman, Applegate and Patterson’s earlier analysis using a smaller sample of the visual database.

However, periods consistent with the KB reports are present from the beginning of the light curve until approximately 2426500. Fourier analysis with the CLEANEST algorithm (Foster 1996b) of data until 2426500 reveals a strong signal at 3076 days (Figure 8). Another strong signal appears around 2436500, this one around $1,530 \pm 94$ days. It only lasts roughly 13,600 days, but it also appears roughly 10,000 days earlier and again 10,000 days later.

A weighted wavelet Z-transform (Foster 1996a) (Figure 7) of the same frequency range with a window size of two full cycles between the inflection points of the Gaussian envelope ($c=0.0125$) shows intermittent presence of various signals. The WWZ is designed to be approximately an F-statistic with non-integer numbers of degrees of freedom. But with a generous quantity of data, it can be treated roughly as chi-square with three degrees of freedom. Hence the values of its peaks are statistically significant, although we express two caveats. First, a significant value does *not* indicate that the data matches a periodic or pseudo-periodic fluctuation, only that it contradicts the null hypothesis (that there is no signal at all, just noise). Second, the stated statistical behavior is for a white-noise process; for red noise the ”critical values” will be higher. Nonetheless, the peaks in the time-frequency plot are at high enough values that we consider them strong evidence of transient pseudoperiodic fluctuation.

We also calculated the time between onset of outbursts in the visual dataset. Due to inconsistent coverage, we ignored the interval 2417586 - 2419339 because we could not be sure an outburst was not missed by the observers. Simply ignoring the gaps during this

interval, as opposed to the entire interval, would have created a selection effect that favored shorter times between outbursts. We found 703 outbursts with an average outburst onset interval of 49.2 ± 15.8 days.

To look for changes in this interval, we averaged the outburst intervals in 500d bins. The result (Figure 9) shows a possible relationship between outburst interval and the 1,000 - 2,000d periods detected in the wavelet analysis. We computed the peak periods via Fourier analysis of 10,000d windows centered on the midpoints of each of the 500d mean bins. We dropped the first and last 10 bins since they had $<10,000$ d of data in them. Finally, we computed a bivariate Pearson Correlation coefficient (Turner 1908) between the peak period and the average outburst intervals. The result was a coefficient of -0.356 , significant to the 0.01 level, which is moderately strong according to Cohen’s guidelines. Thus we conclude there is a moderate negative relationship between the strength of 1,000-2,000d periods in the quiescent visual database and the intervals between outbursts.

4. Conclusion

We have analysed intensive V and I_c band observations of SS Cyg over two observing seasons. We were unable to detect any predictors or other activity which could be used to predict an oncoming outburst. However, the combined uncertainty of our photometric data was high enough to warrant further investigation with more precise observations. In particular, some of the data suggest a rise in the $(V-I_c)$ color beginning five days prior to outburst. The rise level was barely within our uncertainty so we cannot report it. A similar dataset in $(B-I_c)$ may increase the photometric sensitivity to such a feature, if it exists.

We also analysed 102 years of AAVSO visual observations. No periodicity was detected which had not already been reported. However, long term quasiperiodic features were detected on the order of 1,000-2,000 days. Their existence is moderately correlated with shortened intervals between outbursts. If the quasiperiodic features are due to solar type variation, as previously reported, then it is possible that the enhanced activity drives additional mass transfer thus decreasing the mean time between outbursts.

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REFERENCES

- Ak, T., Ozkan, M.T., & Mattei, J.A. 2001, *A&A*, 369, 882
- Bessell, M. S. 1979, *PASP*, 91, 589
- Bianchini, A. 1988, *IBVS*, No. 3136
- Bianchini, A. *Vina del Mar Workshop on Cataclysmic Variable Stars*, ed. by Nikolaus Vogt, 1992. *ASP Conference Series*. 29, p. 284
- Cannizzo, J. K. & Mattei, J. A., 1992, *ApJ*, 401, 642
- Cannizzo, J. K., 1993, *ApJ*, 419, 318
- Cannizzo, J. K. & Mattei, J. A., 1998, *ApJ*, 505, 344
- Collins, P. L. 1999, *J. Amer. Assoc. Var. Star Obs.*, 27, 1
- Cousins, A., 1976, *Mem. R. Astron. Soc.*, 81, 25
- Ferraz-Mello, S. 1981, *AJ*, 86, 619
- Foster, G. 1996, *AJ*, 111, 541
- Foster, G. 1996, *AJ*, 112, 1709
- Giovannelli, Martinez-Pais, I. G., & Sabau Graziati, L. 1992, in *ASP Conf. Ser.* 29, *Vina del Mar Workshop on Cataclysmic Variable Stars*, ed. Nikolaus Vogt (San Francisco: ASP), 119
- Hemplemann, A., & Kurths, J. 1990, *A&A*, 232, 356
- Honey, W. B., Bath, G. T., Charles, P. A., et al. 2005, *MNRAS*, 236, 727
- Hill, R. L. and Waagen, E. O. 2005, *Amer. Astr. Soc. Meeting* 205, #19.08
- Jevtic, N., Mattei, J. A., & Schweitzer, J. S. 2003, *J. Amer. Assoc. Var. Star Obs.*, 31, 138
- Kholopov, P. N. 1985, *General Catalog of Variable Stars*, 4th edition, Moscow
- Kiplinger, A. L., Mattei, J. A., Danskin, K. H., Morgan, J. E. 1988, *J. Amer. Assoc. Var. Star Obs.* 17, 34
- Landolt, A. 1992, *AJ*, 104, 340

Osaki, Y. 1974, PASJ, 26, 429

Price, A., Foster, G., Skiff, B., & Henden, A. 2006, Amer. Astr. Soc. Meeting 209, #162.06

Richman, H. R., Applegate, J. H., & Patterson, J. 1994, PASP, 106, 1075

Turner, H. H. 1908, MNRAS, 68, 544

Turner, R., Price, A., Templeton, M., Waagen, E. O., & Henden, A. 2006, Amer. Astr. Soc. Meeting 209, #162.05.

Voloshina, I. B., & Khruzina, T. S. 2000, Astr. Rep., 44, 2

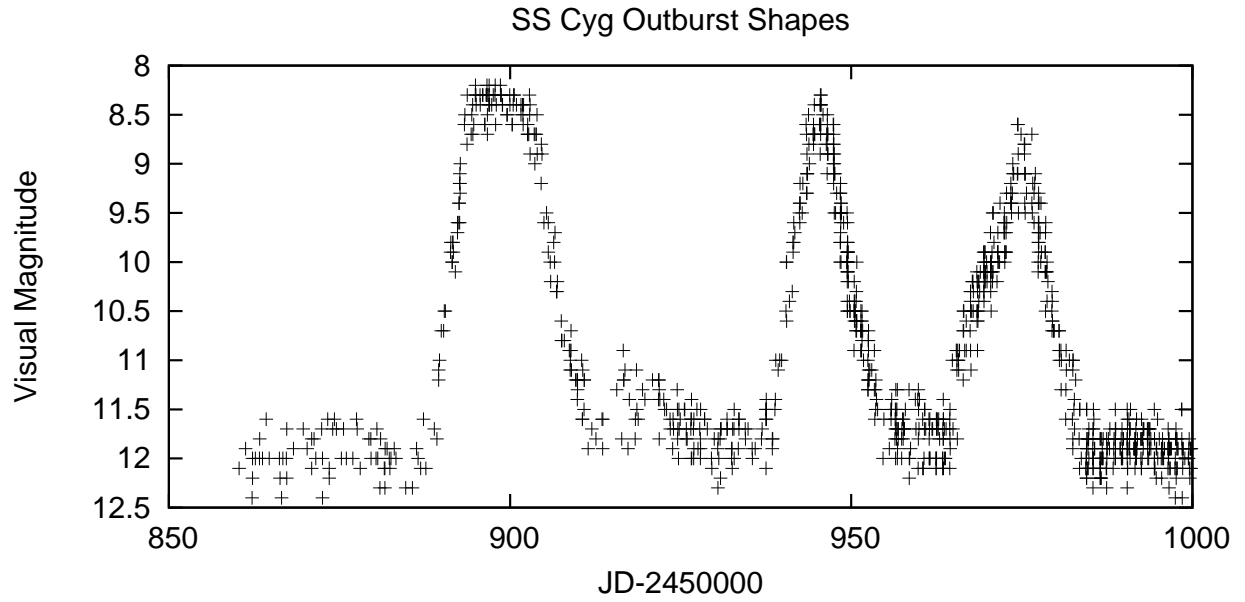


Fig. 1.— A sample of the SS Cyg visual light curve showing the three category of outbursts: long, short and anomalous (left to right).

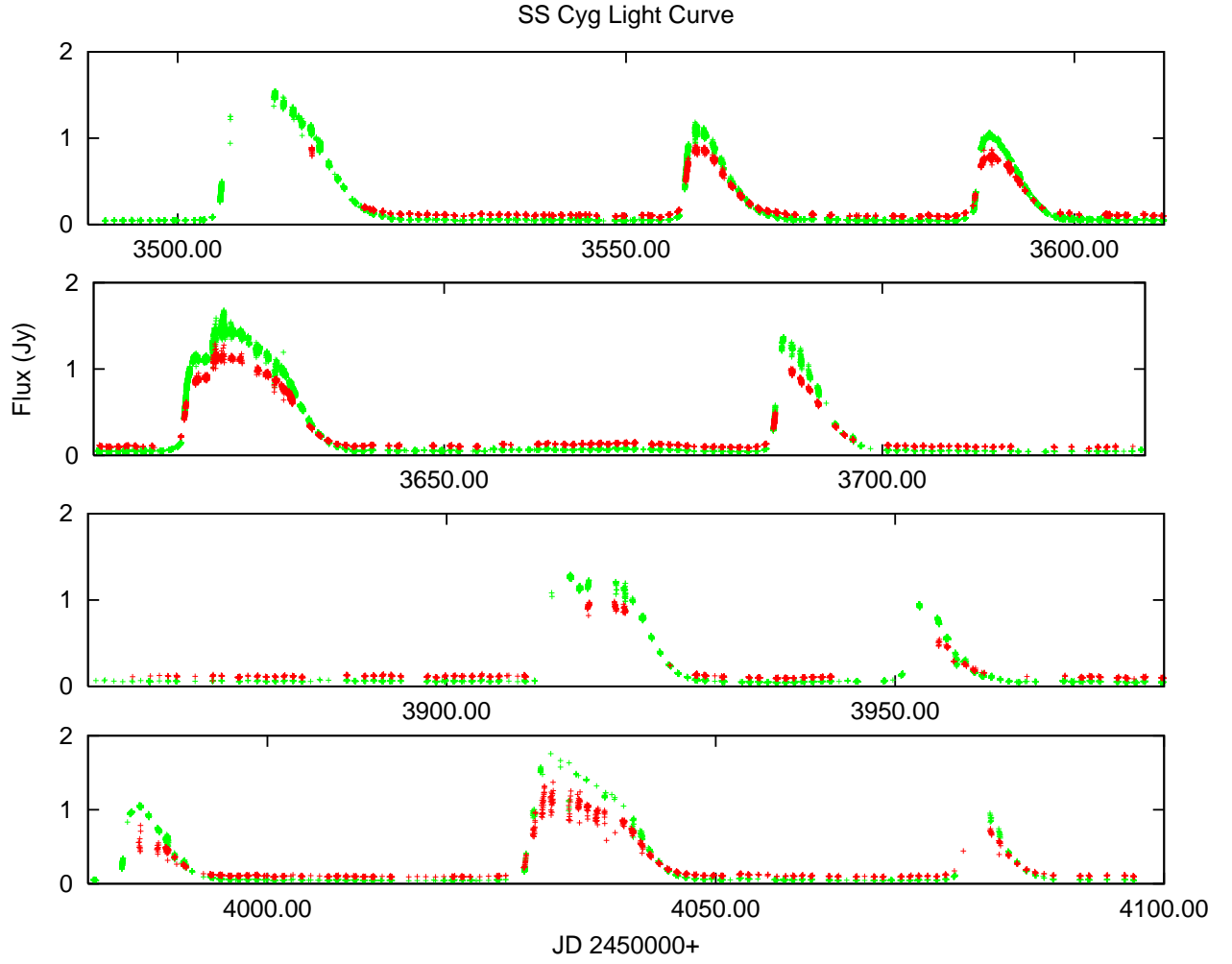


Fig. 2.— V (green) and I_c (red) band photometric light curve for the 2005 and 2006 observing seasons.

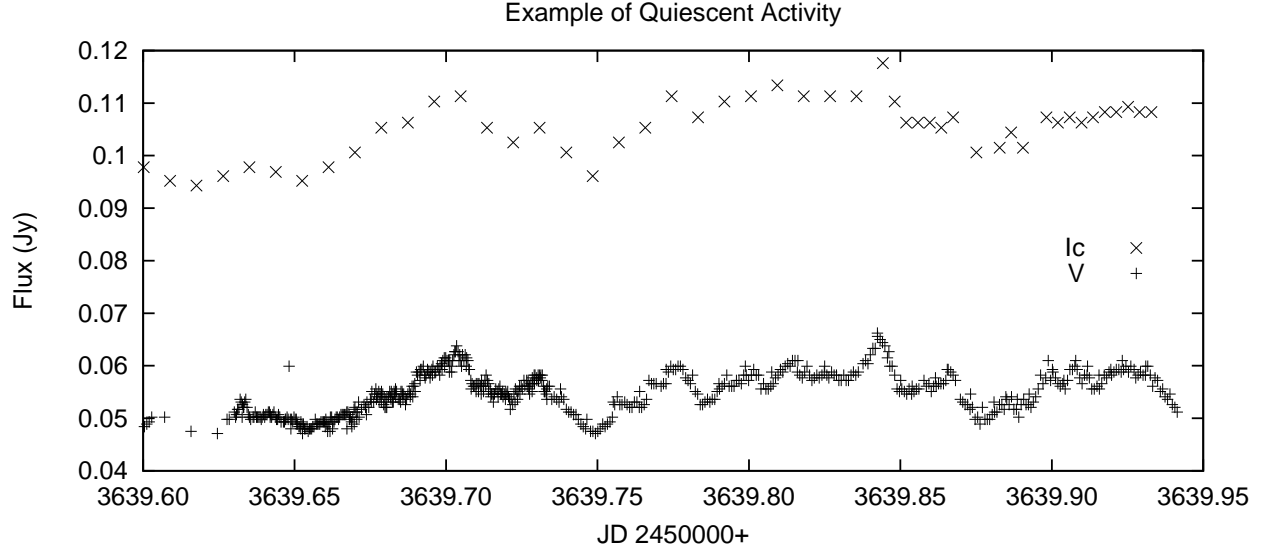


Fig. 3.— A sample of V and I_c flickering in the photometric light curve.

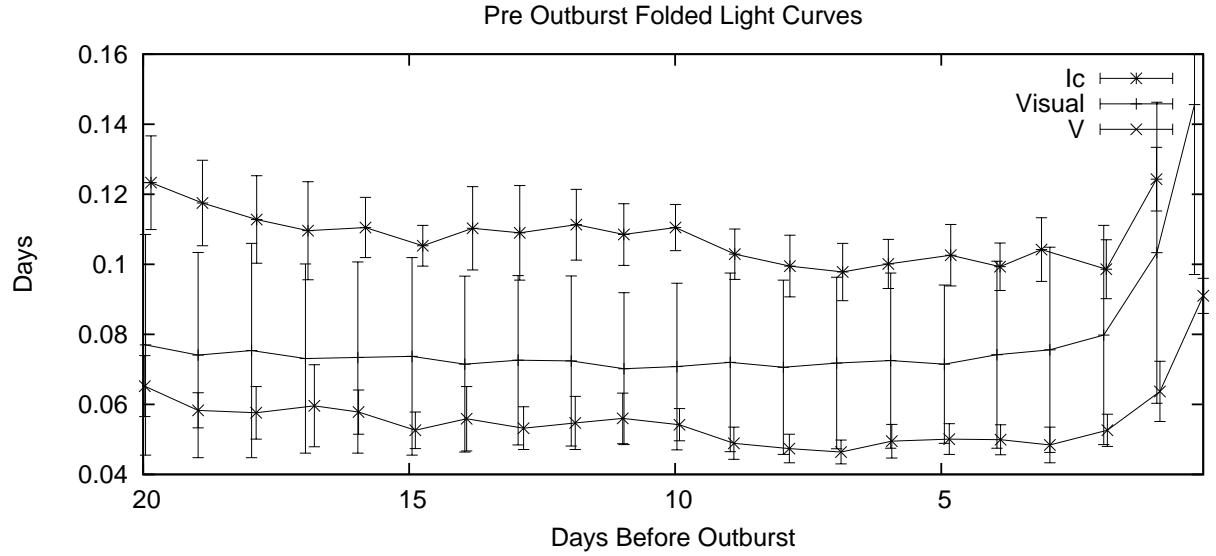


Fig. 4.— V , I_c and visual observations averaged into 1d bins and folded at the start of an outburst.

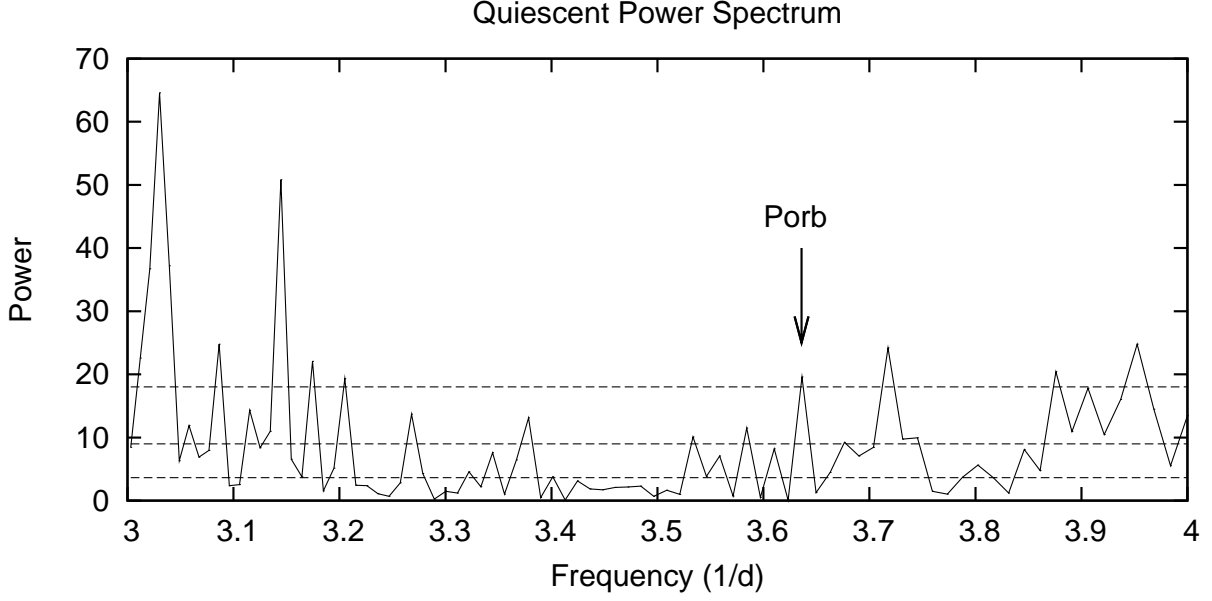


Fig. 5.— Red noise caused by flickering in quiescent observations. The horizontal lines represent 3, 2 and 1 sigma significance (descending).

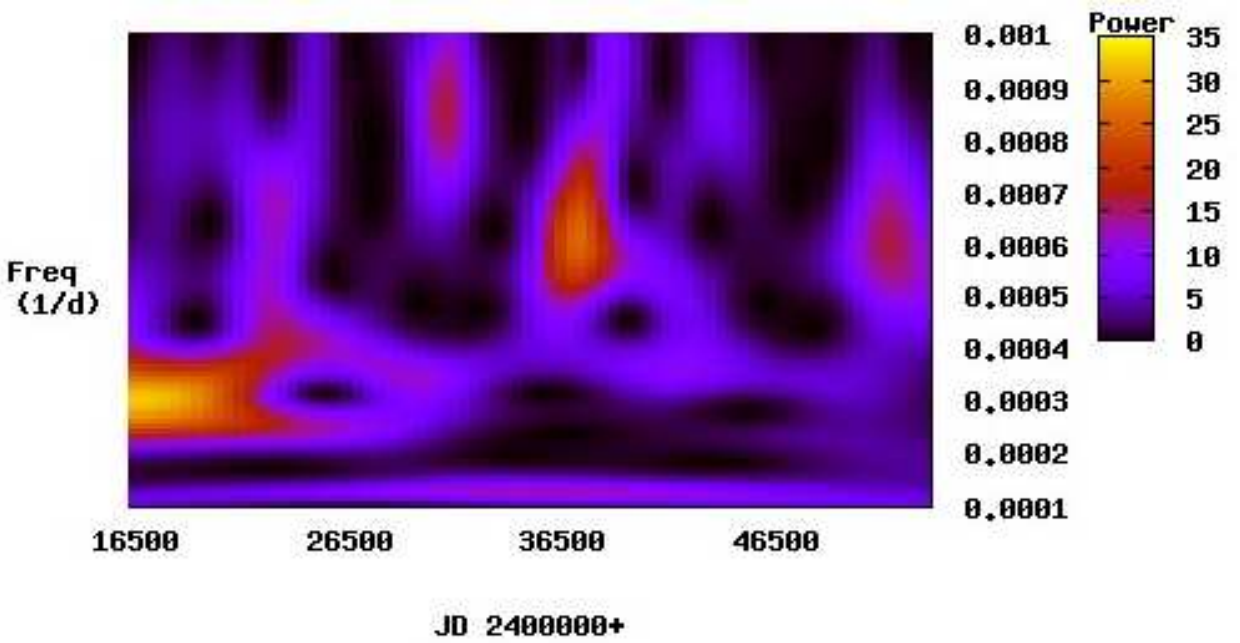


Fig. 6.— Wavelet analysis of 1,000-2,000d quasiperiodic activity in the AAVSO 102 year database of visual observations.

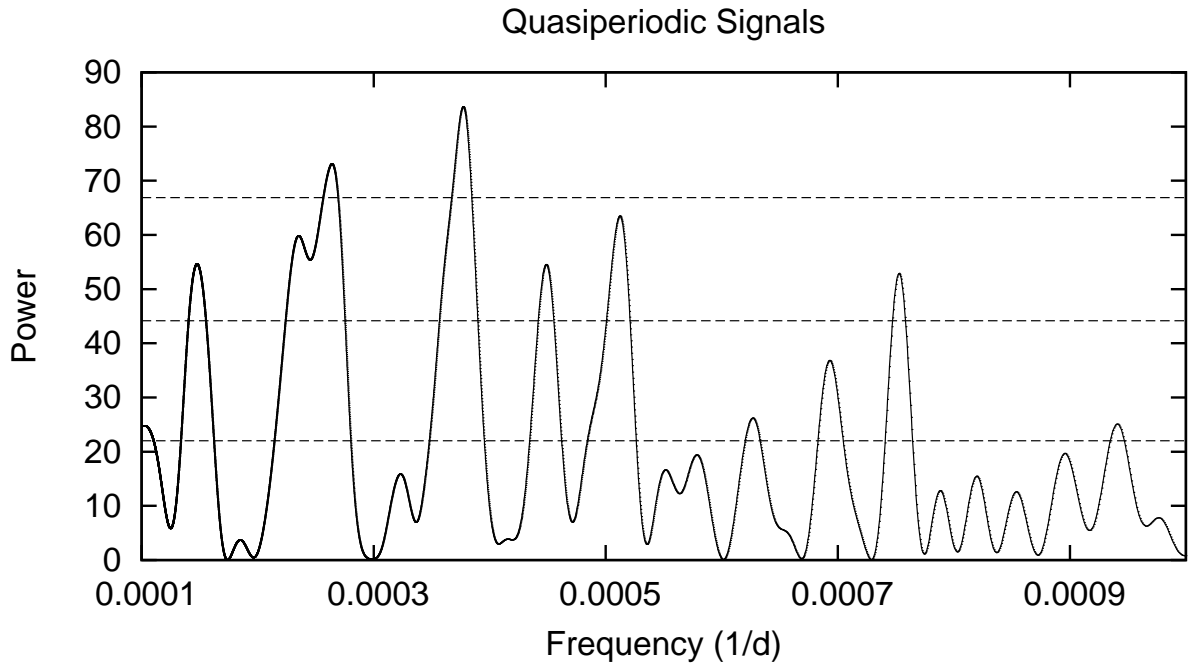


Fig. 7.— Fourier analysis of 1,000-2,000d quasiperiodic activity in the AAVSO 102 year database of visual observations. The horizontal lines represent 3, 2 and 1 sigma significance (descending).

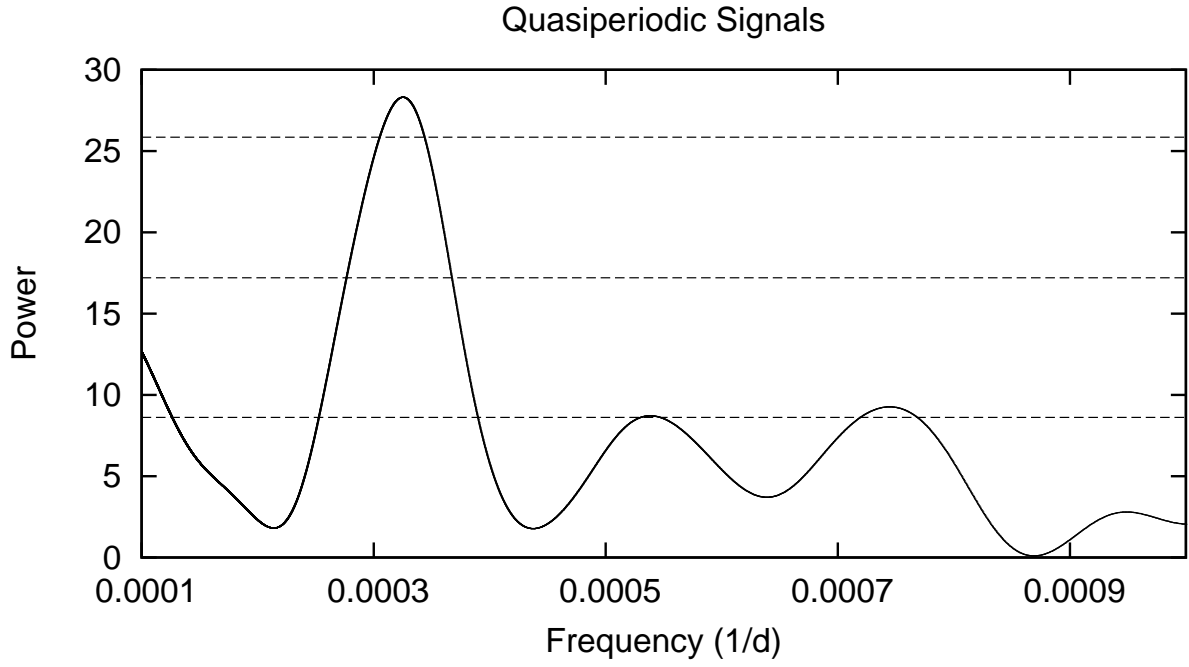


Fig. 8.— Fourier analysis of 1,000-2,000d quasiperiodic activity from to 2416617.7 - 2426500.0. The horizontal lines represent 3, 2 and 1 sigma significance (descending).

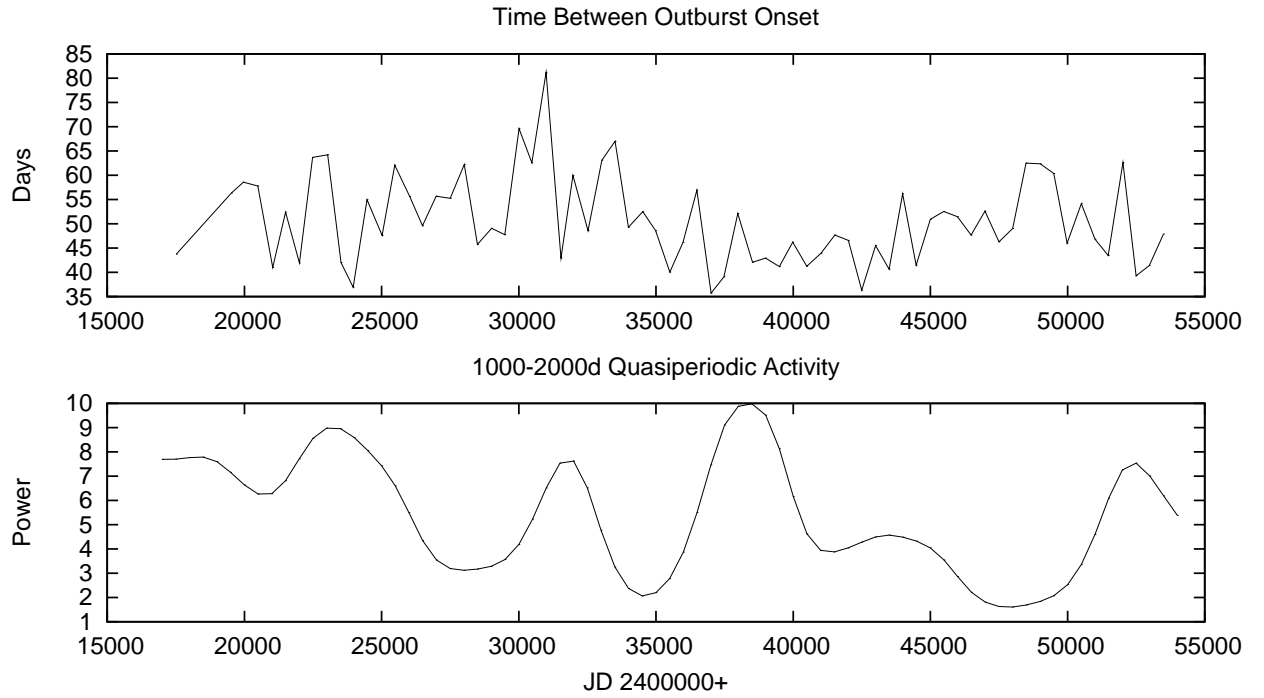


Fig. 9.— Average interval between outburst onsets (500d bins). A moderate bivariate Pearson Correlation coefficient of -0.356 ($p < 0.01$) was found between these averages and the 1,000-2,000d quasiperiodic activity.